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# Timing of surgery for ruptured supratentorial arteriovenous malformations

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## Abstract

**Background** There are conflicting opinions regarding the optimal waiting time to perform surgery after rupture of supratentorial arteriovenous malformations (AVMs) to achieve the best possible outcome.

**Objective** To analyze factors influencing outcomes for ruptured supratentorial AVMs after surgery, paying particular attention to the timing of the surgery.

**Methods** We retrospectively investigated 59 patients admitted to our center between 2000 and 2014 for surgical treatment of ruptured supratentorial AVMs. We evaluated the effect of timing of surgery and other variables on the outcome at 2–4 months (early outcome), at 12 months (intermediate outcome) after surgery, and at final follow-up at the end of 2016 (late outcome).

**Results** Age over 40 years (OR 18.4; 95% CI 1.9–172.1;  $p = 0.011$ ), high Hunt and Hess grade (4 or 5) before surgery (OR 13.5; 95% CI 2.1–89.2;  $p = 0.007$ ), hydrocephalus on admission (OR 12.9; 95% CI 1.8–94.4;  $p = 0.011$ ), and over 400 cm<sup>3</sup> bleeding during surgery (OR 11.5; 95% CI 1.5–86.6;  $p = 0.017$ ) were associated with an unfavorable early outcome. Age over 40 years (OR 62.8; 95% CI 2.6–1524.9;  $p = 0.011$ ), associated aneurysms (OR 34.7; 95% CI 1.4–829.9;  $p = 0.029$ ), high Hunt and Hess grade before surgery (OR 29.2; 95% CI 2.6–332.6;  $p = 0.007$ ), and over 400 cm<sup>3</sup> bleeding during surgery (OR 35.3; 95% CI 1.7–748.7;  $p = 0.022$ ) were associated with an unfavorable intermediate outcome. Associated aneurysms (OR 8.2; 95% CI 1.2–55.7;

$p = 0.031$ ), high Hunt and Hess grade before surgery (OR 5.7; 95% CI 1.3–24.3;  $p = 0.019$ ), and over 400 cm<sup>3</sup> bleeding during surgery (OR 5.8; 95% CI 1.2–27.3;  $p = 0.027$ ) were associated with an unfavorable outcome at last follow-up. Elapsed time between rupture and surgery did not affect early or final outcome.

**Conclusions** Early surgery in patients with ruptured supratentorial arteriovenous malformation is feasible strategy, with late results comparable to those achieved with delayed surgery. Many other factors than timing of surgery play significant roles in long-term outcomes for surgically treated ruptured supratentorial AVMs.

**Keywords** Early outcome · Intermediate outcome · Interval time to surgery · Late outcome · Ruptured AVM · Supratentorial AVM

## Introduction

The definitive treatment of cerebral arteriovenous malformations (AVMs) remains complete microsurgical removal by an experienced surgeon [4, 9, 12, 21, 23, 24, 39, 47, 51, 52]. However, it is considered to be one of the most difficult neurosurgical tasks [1, 52]. The policies of delayed surgery, as well as staged or combined treatments, have been described in previous studies [3, 14, 50]. However, partial obliteration of brain AVM includes a high risk of hemorrhage [22, 23]. Although the number of incidentally discovered AVMs is increasing, acute intracranial hemorrhage remains the most common presenting symptom [2, 13, 30, 31, 49], and AVM is a major cause of hemorrhage in the young [11, 28, 29, 42, 43].

It has been found that the average annual rate of hemorrhage is 2–3% in most studies, but it is highly dependent on

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various risk factors [18, 25, 31, 32, 37, 40, 46, 48, 51], and ruptured AVM harbors a higher rate of re-bleeding [18, 19, 23, 25, 46]. In previous studies, the rate of re-rupture tripled for the first few years, and remained double for decades [16, 18, 28, 36, 46, 48]. During the first year, the risk of re-bleeding may be as high as 16% [17]. There is a higher probability that the next bleeding will occur in the short term [10, 16, 28], and it has a case fatality rate [31, 44, 48].

The timing of surgical treatment for ruptured AVMs has been a controversial topic, and it has been suggested that it may be beneficial to delay this treatment until the edema has subsided and the clinical condition of the patient has improved [6, 20]. The fact that AVMs are less prone than, for example, intracranial aneurysms to re-bleed very early has been used to support this suggestion. However, from the surgical perspective, fresh AVM bleeding may even facilitate surgical resection; a hematoma cavity offers a wide corridor and creates a good cleavage plane, and bleeding itself releases a high flow inside the nidus [24, 33, 47]. Several neurosurgeons have rationalized early surgery on the basis that ruptured AVMs may cause a life-threatening mass effect, due to expansive hematoma [5, 7, 27, 38, 45, 51]. In addition to removal of the clot, surgical treatment of the AVM can remove the lesion and immediately eliminate the risk of a new hemorrhage. Immediate eradication of the AVM may also facilitate the rehabilitation of the patient, whereas in the case of delayed treatment, the patient must recover twice: first from the hemorrhage, and later from the AVM treatment. It has long been our policy to treat ruptured AVMs without unnecessary delays after the necessary preoperative investigations have been carried out; in unconscious patients with life-threatening hematomas within a few hours, and usually within few days in others.

In the present study, we reviewed our recent experience of surgical treatment of ruptured supratentorial AVMs and analyzed the clinical outcomes, with regard to different time intervals between rupture and surgery. The timing of surgery was analyzed together with other factors that potentially affect outcomes.

## Methods

The data were retrospectively retrieved from the Helsinki AVM Database, Finland, which includes all patients with brain AVMs who have been admitted to the Department of Neurosurgery at Helsinki University Hospital, Helsinki, Finland, since 1942 (805 patients had been admitted by the end of 2014), with a population responsibility and current catchment area of 1.8 people. The ethical committee of the Helsinki University Hospital approved the study.

## Patient selection and clinical data

The main selection process began by the selection of patients with ruptured supratentorial AVMs who had been admitted from 2000 to 2014, with a maximum delay of 1 year between the rupture and AVM surgery. The patients were followed up until death or during 2016. Those treated before 2000 were excluded because the original imaging was not necessarily available for review. Ending inclusion at the end of 2014 allowed a minimum of 1 full year of follow-up, with a survey performed during 2016. Infratentorial AVM patients were excluded, because infratentorial hemorrhage often necessitates immediate surgery, and timing is less controversial. We analyzed only patients who had been operated on by one of the senior authors (J.H.), who performed the vast majority of AVM operations during the study period in our center, to minimize variability caused by surgeon experience.

In addition, the following exclusion criteria were applied to patient selection, to minimize confounding factors potentially affecting clinical outcomes or data analysis:

- 1- Foreign patients leaving Finland immediately after treatment, that is, no structured late follow-up data were reliably available
- 2- Uncertain timing of AVM rupture
- 3- Surgery for an AVM had not been planned, that is, the AVM diagnosis was initially missed and made only peri- or postoperatively in a patient operated on for what was initially thought to be a spontaneous intracerebral hemorrhage
- 4- The AVM ruptured after/due to another modality of treatment (embolization or radiotherapy) had been received for an originally unruptured AVM.
- 5- Cases in which the AVM was not the source of the hemorrhage (AVM-unrelated bleeding in an AVM patient)
- 6- Patients who had severe heart failure or cancer

The timing of surgery in this retrospective cohort was dependent on many factors, including the clinical condition, the referral policy of the referring hospitals, surgeon discretion and availability, and patient-family agreement. The surgical procedure included cautious dissection and identification of all of the vessels in the vicinity of the AVM, carefully saving the draining vein until the end of the removal, and thorough inspection of the resection bed, as well as securing the final steps of hemostasis, using “dirty coagulation” of tiny deep feeders [24].

Diagnosis of AVM and hemorrhage was usually based on computed tomography (CT) and CT angiography (CTA), or magnetic resonance imaging (MRI). Four-vessel digital subtraction angiography (DSA) was always performed, unless the clinical condition required immediate emergency evacuation of the hematoma, in which cases AVM diagnosis was based

on CTA. Total excision of the AVM was verified by postoperative DSA in 95% of the cases.

Pre and perioperative clinical and demographic data were collected from hospital records, and anatomical details were evaluated from the original imaging and the radiologist's reports. Since there are no AVM rupture-specific grading scales, we used Hunt and Hess score to rate the clinical condition of the patients upon arrival and immediately before surgery. It is based on patient's clinical neurological condition, taking into account the presence of focal deficits (usually caused by intraparenchymatous hematoma), and the level of consciousness dictated mainly by the severity of the bleeding. The outcome was based on hospital records as follows: using the Glasgow Outcome Scale (GOS) at 2–4 months (early outcome) and at 12 months (intermediate outcome) after surgery, and the modified Rankin Scale (mRS), based on questionnaires completed by patients or relatives in 2016 (final outcome) for the patients who were alive. The early and 12-month outcomes were estimated from hospital records using the Glasgow Outcome Score (GOS), which can be reliably evaluated from the available data even retrospectively. For the late follow-up, the mRS are based on actual questionnaires designed to evaluate time-specific mRS scores.

The date and cause of death of deceased patients was obtained from Statistics Finland (a Finnish public authority that maintains nationwide registries).

### Statistical analysis

We performed univariate analyses to evaluate the associations between each variable and outcome at different time points (as described above). Pearson Chi-square tests were performed to compare categorical variables, and the Mann–Whitney *U* test was used to compare continuous variables. In order to evaluate independent factors affecting outcome, a binary logistic regression model was constructed, using the Wald method (first entering variables into the model and then using stepwise backward elimination). Stepwise logistic regression was used in multivariate analysis to identify independent predictors of dichotomized outcomes (favorable vs. poor, defined as GOS 1–2 vs. 3–5, or mRS 0–2 vs. 3–6). The association between the timing of surgery and duration of intensive care unit (ICU) treatment was studied using Spearman's non-parametric correlation. The statistical tests were two-sided, and  $p < 0.05$  was considered statistically significant. The statistical analysis was performed using Statistical Package for the Social Sciences software, version 22 (SPSS Inc., Chicago, IL, USA).

### Results

Of the 805 patients attending our department with brain AVM between 1942 and 2014, 59 met the inclusion criteria. Full

patient-related information on admission is presented in Tables 1 and 2, and perioperative information is shown in Table 3. The mean age of the patients was 40.5 years (SD 18.8 years), 30 were male (51%) and 29 were female (49%). The majority attended with neurological deficits (40% severe, 25% mild). Twelve (20%) developed hydrocephalus before surgery, and nine (15%) presented with epilepsy.

The median maximum diameter of hemorrhage was 44 mm (SD, 24.7, range, 0–80). Intraventricular bleeding was observed in 26 (44%) patients. Re-bleeding before surgery occurred in three patients (see below for further details). The AVM size was over 30 mm in 20 (34%) cases. The AVM was located in a deep position in 22 (37%) patients, and the nidus was diffuse in 12 (20%) cases. The AVM was located in an eloquent area in 29 (49%) patients. Deep venous drainage was present in 13 (22%) cases, 14 (24%) AVMs were fed by deep perforators, and flow-related aneurysms were observed in seven (12%) cases.

The median time from AVM rupture to surgery was 2 days (range, 0–360 days). A total of 37 (62%) patients underwent surgery within 4 days of rupture. Surgery was performed on the day of bleeding (day 0) in 18 (30%) patients. In 13 (22%) patients, the AVM was embolized before surgery. The average amount of bleeding during surgery was 448 cm<sup>3</sup> (SD, 1045 cm<sup>3</sup>, range, 50–7000 cm<sup>3</sup>). Only nine (15%) patients required a blood transfusion. We achieved total exclusion of the AVM at first surgery in 57 patients (96%). One patient underwent a further operation because of re-bleeding from the resection bed of the AVM following surgery. The patient showed a worse post-operative result and had died before early follow up (2–4 months). Another patient had a second operation because of residual filling of the AVM. This patient, who had presented with a focal neurological deficit at admission, improved slowly to have moderate disability at final follow-up.

Three patients (5%) died in hospital due to AVM-related reasons during first hospitalization. Another six (10%) patients died before final follow-up (2016), two as a result of AVM-related complications. In univariate analysis (Table 4), poor early outcome (GOS at 2–4 months) was significantly

**Table 1** Descriptive statistics for continuous variables for the 59 patients who met the inclusion criteria

	Median/mean	SD	SEM	Range
Age, years	40 /40.5	18.8	2.4	0–71
Hunt and Hess at admission	4 /4.1	1.2	0.2	1–6
Hematoma largest diameter, mm	44 /38.9	24.7	3.2	0–80
Rupture to surgery, days	2 /30.0	72.3	9.4	0–360
ICU days	5 /7.3	5.5	0.7	0–23
Hospital days	12 /13.1	7.1	0.9	2–30

SD standard deviation, SEM standard error of the mean

**Table 2** Descriptive statistics for categorized variables for the 59 patients who met inclusion criteria

Factor	Categories	Frequency	Percent
Gender	Male	30	51
	Female	29	49
Embolization before surgery	Yes	13	22
	No	46	78
Spetzler–Martin grade	<3	31	53
	=3	16	27
	>3	12	20
Supplemented Spetzler–Martin grade	<6	35	59
	=6	10	17
	>6	14	24
AVM size, cm	< 3 cm	39	66
	> 3 cm	20	34
Location	Deep	22	37
	Superficial	37	63
Hydrocephalus at admission	Yes	12	20
	No	47	80
Epilepsy at admission	Yes	9	15
	No	50	85
Nidus	Diffuse	12	20
	Compact	47	80
Eloquence	Yes	29	49
	No	30	51
Venous drainage	Deep	13	22
	Cortical	32	54
	Deep and cortical	14	24
Perforator	Yes	14	24
	No	45	76
AVM flow-related aneurysm	Yes	7	12
	No	52	88
Intraventricular blood	Yes	26	44
	No	33	56
Amount of bleeding during surgery	< 400 cm <sup>3</sup>	47	80
	> 400 cm <sup>3</sup>	12	20
Bleed transfusion	Yes	9	15
	No	50	85
Immediate post operation result	Better	12	20
	Worse	16	27
	Same	31	53
2–4 months GOS	Favorite	43	73
	No	16	27
12 month GOS	Favorite	44	75
	No	15	25
Last mRS follow-up (end 2016)	Favorite	44	75
	No	15 (9 dead)	25
Days at hospital	<14	24	41
	>14	35	59
ICU days	<7	34	58
	>7	25	42

**Table 3** Treatment-related information and in-hospital complications

Situation	N
Acute hydrocephalus before surgery	12
Another bleeding before surgery	3
Severe focal neurological deficits	24
Mental deterioration	10
Pre-surgery other problem (respiratory (2), high blood pressure (10), kidney (1), psychological (3), coagulopathies (2), urinary infection (3), diabetics (3), atherosclerosis (5), gastrointestinal (1))	*
Surgery done at the same day of rupture (0 day)	18
Surgery done within 4 days of rupture	37
Permanent ligation major vessel during surgery	1
Temporary ligation vessel during surgery	10
Thrombosis efferent vessel	1
Post-operative subdural hematoma	2
Post-operative intracerebral hematoma	3
More than one surgery (hematoma, shunt...)	11
More than one surgery for the AVM	2
Total excluded by first surgery	57
Death related to AVM after ruptured during first hospitalization	3
All deaths at last follow-up (2016)	9
Postoperative venous thrombosis (leg)	3
Post-operative arterial spasm	4
Use of epileptic drug at any time (8 just loading dose)	40
New using of epileptic drug after surgery	7
Post-operative new hydrocephalus (1 shunting, 3 ventriculostomy)	4
Post-operative sepsis	2
Post-operative meningitis	2
Wound infection	1

\*There is overlapping

associated with age > 40 ( $p = 0.004$ ; OR 6.6), deep perforators ( $p = 0.027$ ; OR 4.0), associated aneurysms ( $p = 0.004$ ; OR 9.3), focal neurological deficits ( $p = 0.050$ ; OR 3.1), hydrocephalus before surgery ( $p = 0.000$ ; OR 2.1), hypertension at admission ( $p = 0.010$ ; OR 1.2), bleeding over 400 cm<sup>3</sup> during surgery ( $p = 0.047$ ; OR 3.7), and high preoperative Hunt and Hess grade (4 or 5) ( $p = 0.000$ ; OR 9.6).

Poor intermediate outcome (GOS at 12 months) analysis revealed a significant univariate association with age > 40 ( $p = 0.001$ ; OR 10.3), associated aneurysms ( $p = 0.000$ ; OR 28.6), high Hunt and Hess grade before surgery ( $p = 0.001$ ; OR 7.8), hydrocephalus ( $p = 0.029$ ; OR 4.2), and bleeding more than 400 cm<sup>3</sup> during surgery ( $p = 0.003$ ; OR 6.8). Poor final outcome (mRS >2 at final follow-up in 2016) was associated with age > 40 ( $p = 0.044$ ; OR 3.6), associated aneurysms ( $p = 0.002$ ; OR 10.5), high Hunt and Hess grade before surgery ( $p = 0.007$ ; OR 5.1), bleeding > 400 cm<sup>3</sup> during surgery ( $p = 0.003$ ; OR 6.8), and nidus diffuseness ( $p = 0.029$ ; OR 4.2).

In a multivariate logistic regression model for poor early outcome, stepwise (Walt) backward elimination identified four main factors with significant effect (Table 5).

Significant factors were age > 40 ( $p = 0.011$ ; OR 18.4), high Hunt and Hess grade before surgery ( $p = 0.007$ ; OR 13.5), hydrocephalus before surgery ( $p = 0.011$ ; OR 12.9), and more than 400 cm<sup>3</sup> of bleeding during surgery ( $p = 0.017$ ; OR 11.5). For poor intermediate outcome, the significant factors were age > 40 ( $p = 0.011$ ; OR 62.8) associated aneurysms ( $p = 0.029$ , OR 34.7), high Hunt and Hess grade before surgery ( $p = 0.007$ ; OR 29.2), and more than 400 cm<sup>3</sup> of bleeding during surgery ( $p = 0.022$ ; OR 35.3) (Table 6).

For poor final outcome, significant factors were associated aneurysms ( $p = 0.031$ ; OR 8.2), high Hunt and Hess grade before surgery ( $p = 0.019$ ; OR 5.7), and more than 400 cm<sup>3</sup> of bleeding during surgery ( $p = 0.027$ ; OR 5.8) (Table 7).

Time interval from bleeding to surgery was not significantly associated with outcome at any time points, according to univariate or multiple regression analyses. Moreover, a non-parametric Spearman correlation was not significant between time interval to surgery and the number of days spent in the ICU ( $p = 0.82$ , Spearman's rho interval bleeding to surgery correlation coefficient 1.000). We also analyzed the influence of timing to surgery in only those 40 patients, where preoperative Hunt and Hess score was 3 or less (i.e., conscious



**Table 4** Univariate analysis of variables associated with worse 2–4 months GOS (early outcome), 12-months GOS (moderate outcome), and last mRS follow-up 2016 (late outcome)

Factor	Association with worse (early outcome), <i>P</i> value/OR	Association with worse (moderate outcome), <i>P</i> value/OR	Association with worse (late outcome) <i>p</i> value/OR
Age > 40	<b>0.004/6.6</b>	<b>0.001/ 10.3</b>	<b>0.044/3.6</b>
Gender	0.218	0.713	0.339
Hypertension	<b>0.010/1.2</b>	0.253	0.253
Epilepsy at admission	0.652	0.815	0.823
Focal neurological deficit at admission	<b>0.050/3.1</b>	0.113	0.328
Hydrocephalus before surgery	<b>0.000/2.1</b>	<b>0.029/4.2</b>	0.489
Blood in ventricle	0.234	0.341	0.341
Re-bleeding before surgery (3 cases)	0.760	0.094	0.094
Hematoma larger diameter<40 mm>	0.651	0.159	0.833
Hunt and Hess on admission<4>	0.306	0.130	0.392
Preoperative Hunt and Hess<4>	<b>0.000/9.6</b>	<b>0.001/7.8</b>	<b>0.007/5.1</b>
Embolization before surgery	0.716	0.829	0.829
AVM size in mm	0.732	0.993	0.292
Venous drainage	0.258	0.818	0.411
Deep perforator	<b>0.027/4.0</b>	0.089	0.089
Associated aneurysm	<b>0.004/9.3</b>	<b>0.000/28.6</b>	<b>0.002/10.5</b>
AVM location (Superficial/ deep)	0.068	0.142	0.393
Nidus (compact/ diffuse)	0.211	0.153	<b>0.029/4.2</b>
Eloquence location	0.514	0.339	0.827
Bleeding during surgery > 400	<b>0.047/3.7</b>	<b>0.003/6.8</b>	<b>0.003/6.8</b>
Interval time to surgery, days	0.392	0.348	0.823
Surgery within 4 days of rupture	0.392	0.333	0.719

Numbers in bold specify a significance *p*-value < 0.05

patients) which should exclude those critically ill high-grade patients who will need immediate emergency operation because of large expansive hematomas. Even in this subcohort, the time to surgery in univariate analyses (analyzed in the same way as for whole cohort) did not show any effect.

The outcome for the three patients who had early re-bleeding before surgery was as follows: the first patient was 60 years old, with a deep 27 mm AVM associated with a small pericallosal aneurysm, and presented with a severe headache and focal neurological deficit. The second bleeding occurred after 3 months. The final outcome was not favorable, with severe disability. The second patient, who was aged 71 years and had a small temporal

cortical AVM, presented with focal deficits and was operated on after 4 days with a new bleed. The final outcome was favorable, with moderate disability. The third patient, aged 21 years and with a basal ganglion AVM, bled again after 6 months with intraventricular bleeding, and was dead after 9 months.

Embolization before surgery did not show a significant influence on early, moderate, or late outcomes (*p* = 0.716, 0.829, and 0.829, respectively) Table 4. However, related variables of the preoperative embolized and non-embolized cases were analyzed; the AVM characteristics, surgical aspects, and outcomes are presented in Table 8.

**Table 5** Factors significantly associated with worse early outcome in multiple logistic regression model (Walt stepwise backward model)

Factor	<i>P</i> value	OR	95% CI
Age > 40	0.011	18.4	1.9–172.1
Hunt and Hess before surgery >4	0.007	13.5	2.1–89.2
Hydrocephalus at admission	0.011	12.9	1.8–94.4
Bleeding during surgery > 400 cm <sup>3</sup>	0.017	11.5	1.5–86.6

OR odds ratio, CI confidence interval

**Table 6** Factors significantly associated with worse intermediate (12 months) outcome in multiple logistic regression model (Walt stepwise backward model)

Factor	<i>P</i> value	OR	95% CI
Age > 40	0.011	62.8	2.6–1524.9
Associated aneurysm	0.029	34.7	1.4–829.9
Hunt and Hess before surgery	0.007	29.2	2.6–332.6
Amount of bleeding during surgery	0.022	35.3	1.7–748.7

OR odds ratio, CI confidence interval

**Table 7** Factors significantly associated with worse late outcome in multiple logistic regression model (Walt stepwise backward model)

Factor	<i>P</i> value	OR	95% CI
Associated aneurysm	0.031	8.2	1.2–55.7
Hunt and Hess before surgery	0.019	5.7	1.3–24.3
Amount of bleeding during surgery	0.027	5.8	1.2–27.3

OR odds ratio, CI confidence interval

## Discussion

Surgical intervention is considered to be a definitive strategy for the treatment of ruptured cerebral AVM, providing immediate cure and prevention of rebleeding [8]. However, there is a lack of consensus regarding the timing of the operation, and it remains a subject of considerable variation in clinical practice. There are two basic approaches to ruptured AVM treatment. The first of these is a primary surgical approach at an early stage, and the second is a primary conservative treatment, followed by delayed surgical, endovascular, or radiosurgical intervention, or a combination thereof. However, emergency craniotomy may be life-saving, and is the only appropriate solution in many cases [26].

We conducted a retrospective analysis of surgically treated ruptured supratentorial AVMs to evaluate the influence of timing of surgery on early and late outcome. Deep perforators, high Hunt and Hess grade before surgery, age over 40, hydrocephalus, amount of bleeding during surgery, and AVM-related aneurysms were associated with an increased likelihood of poor surgical outcomes. The homogenous selection of our study population, as well as utilization of a multivariate model, aimed to enable the analysis of the time interval between bleeding and surgery as a potential predicting factor with regard to outcome, among other potential prognosticators. In this cohort, the time interval between AVM bleeding and surgery did not influence early or late outcome, and the role of those factors that did affect outcome are primarily understandable. For example, it is not surprising that

increasing age, increasing bleeding severity (as assessed using Hunt and Hess grade), or the presence of hydrocephalus were associated with a worse outcome. It is known that the presence of deep perforators makes AVM surgery more challenging [15], and the greater amount of blood loss during surgery is likely indicative of larger and more complex lesions.

In the early era of microsurgical AVM treatment, acute intervention for ruptured AVMs was considered relatively contraindicated, as the risk of each recurrent hemorrhage from AVM was comparable with the same risk from a re-ruptured aneurysm [34]. This opinion originated from a concern of potentially damaging the brain tissue on a confusing hemorrhagic background. This was the main reason that non-surgical therapy was more frequently chosen, and for the delay of surgical intervention until the hematoma had subsided. As experience in microsurgical AVM treatment increased, the degree of peri-nidal brain injury decreased, and the willingness to target these lesions earlier after hemorrhage also increased. This initiated the discussion concerning the correct timing of microsurgical dissection of the cerebral AVM. Few studies have focused on the optimal timing of this operation. However, early surgery for ruptured cerebral AVM, even within a timeframe of a few hours or days, may currently be considered in experienced centers. However, others recommend emergency hematoma evacuation with delayed AVM excision as a safe strategy in certain situations [35]. Although a 4-week interval has been recommended in some studies, the exact waiting period remains controversial [6, 35].

Our study showed that there appears to be no significant advantage in delaying surgical treatment for ruptured supratentorial AVMs, as the long-term outcomes for immediately/early treated patients were comparable to those treated after longer delays. This is despite the fact that those patients with life-threatening hematomas, and therefore in the poorest initial clinical condition, were naturally treated with minimal delays. In contrast, early surgical intervention may (1) facilitate early rehabilitation, (2) decrease the likelihood of reappearance of focal neurological deficits upon surgery, as may well happen if performed after the initial recovery period

**Table 8** Pre-operation embolized and not embolized AVM characteristics, surgical aspects, and outcome

	Embolized AVM (13 cases)	Non embolized AVM (46 cases)
AVM >30 mm	8	4
Deep vein	11	15
Deep perforator	7	7
Nidus (diffuseness)	6	6
Bleeding > 400 cm <sup>3</sup> during surgery	6	6
Within 4 days (ruptured to surgery)	6	31
Early favorite outcome	10*	33*
Moderate favorite outcome	10*	34*
Late favorite outcome	10*	34*

\*Embolized AVMs have no different percentage outcome



(often temporary, but still requiring a new rehabilitation period), (3) prevent the risk of re-bleeding during the recovery period while waiting for definitive treatment, and (4) decrease medical expenses. For decades, it has been the policy of one of the senior authors (J.H.) to treat ruptured AVMs without delay whenever possible, and, with experience, the surgery is definitely feasible, even in these acute situations. In most urgent situations, surgery must be performed using only the information given by CT and CTA, but usually the condition of the patient allows the performance of DSA. In selected cases, preoperative Onyx<sup>R</sup> embolization may facilitate surgical treatment. Preoperative MRI may also be beneficial for surgical planning, if the patient's condition allows. During surgery, the correct neuroanesthesiological principles [41] are mandatory to control blood pressure and to provide "slack brain" to optimize the microsurgical circumstances. Postoperative DSA control is performed on the same, or, at the latest, the next, day to verify complete eradication of the lesion. After AVM resection and hematoma evacuation, controlled hypotension is administered at the ICU, the duration and depth of which depends on the complexity and size of the lesion. We usually aim for < 100 mmHg at least for the first 24 h after surgery, unless compromised cerebral perfusion pressure necessitates higher systemic blood pressure.

Our results still keep the door open for either strategy, depending on the individual patient and the experience of the team. However, with sufficient microsurgical experience, early surgery for ruptured AVMs is certainly feasible and can be justified for the above-mentioned reasons. Obviously, life-threatening hematomas necessitate immediate intervention, and our recommendation is to eradicate the AVM in the same operation, if possible. Avoiding peri- and postoperative complications and optimizing ICU treatment are also likely to influence outcomes.

**Limitations of the study** Although the strict inclusion criteria decreased the influence of potential confounding factors, it limited our patient population and may have introduced some selection bias to the cohort. However, potential selection bias was decreased by the fact that ours is the only neurosurgical referral center for our catchment area (1.8 million people). We chose cases of a single experienced neurosurgeon, in order to minimize surgeon experience as a confounding factor. However, this may limit the generalizability of the findings. Prospective studies involving a larger number of neurosurgeons and centers are required to validate the findings of this study.

## Conclusions

The present study showed that the time interval from AVM rupture to surgery did not affect long-term outcomes. The

optimal timing of surgery for ruptured supratentorial AVMs remains unestablished, but since delayed surgery does not appear to produce any advantage, we recommend early surgery to facilitate early rehabilitation and to prevent early re-bleeding.

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## Compliance with ethical standards

**Conflict of interest** None.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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## Comments

We have here a study from a renowned senior surgeon and an experienced group regarding early surgery approach to ruptured intracranial AVMs. The analysis is done on 59 patients culled from a total experience of 805 patients. It is a fractional sample of the overall group, but this is because careful steps were taken to ensure a complete dataset in analyzed patients. The data is instructive even though it is a small subset of the Helsinki AVM experience.

The raw data is impressive, no doubt because of the quality of this highly experienced team and center, and their ability to transfer patients quickly from throughout Finland. Mean time to surgery was 2 days. Complete excision at first surgery was achieved in 96% of patients. Mortality was 15%. Deep perforators, high Hunt-Hess grade before surgery (note that they have used Hunt and Hess grading for AVMs in the absence of a truly dedicated AVM hemorrhage acuity grading system), age over 40, hydrocephalus, amount of bleeding during surgery, and AVM-related aneurysms were associated with an increased likelihood of poor surgical outcomes. Importantly, neither time to surgery nor embolization before surgery were associated with significant differences in outcome.

This study impacts the practice of AVM surgery in several important ways. Unlike aneurysmal subarachnoid hemorrhage, in this series a policy of early AVM surgery is neither better nor worse than a policy of delayed surgery, except of course where life-threatening ICH and mass effect are present, and early surgery is thus mandated. The study also codifies that risk factors which AVM surgeons know intuitively to be negative predictors of outcome, like excessive bleeding, deep feeders, poor patient condition and the others outlined above, are validated by this analysis.

The only reservation about this paper is that of course this is a tiny subset of the extensive Helsinki experience. However, we can understand why they chose to do it this way, to obtain the best possible dataset, and we accept and recommend the article as a quality observation of many things, but especially that early AVM surgery is reasonable and can be associated with similar outcomes to delayed surgery if the team and facility is available and the surgeon elects this practice.

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